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Letter to the Hon. R. W. Thompson, Secretary of the Navy, announcing the Discovery of Satellites of Mars.

U.S. NAVAL OBSERVATORY, WASHINGTON,
August 21, 1877.

Sir,—The outer satellite of *Mars* was first observed by Professor Asaph Hall, U.S.N., on the night of August 11, 1877. Cloudy weather prevented the certain recognition of its true character at that time. On August 16 it was again observed, and its motion was established by observation extending through an interval of two hours, during which the planet moved over thirty seconds of arc.

The inner satellite was first observed on the night of August 17, and was also discovered by Professor Hall.

On Saturday, August 18, the discoveries were telegraphed to Alvan Clark & Sons, Cambridgeport, Mass., in order that if the weather should be cloudy at Washington, they might confirm the existence of the satellites with the 26-inch telescope of Mr. McCormick, which is in their hands.

This discovery was confirmed by Professor Pickering and his assistants, at Cambridge, Mass., and by the Messrs. Clark, at Cambridgeport.

On August 19, the discovery was communicated to the Smithsonian Institution, by which it was announced to the American and European observatories in the following despatch :—

Two satellites of Mars discovered by Hall, at Washington. First, elongation west, August 18, *eleven hours, Washington time. Distance, eighty seconds. Period, thirty hours. Distance of second, fifty seconds.*

It will be seen hereafter that the statement of fifty seconds as the distance of the inner one was erroneous.

The observations hitherto made are as follow :—

The First Satellite.

	h m	°	h m	"		Observer.
1877, Aug. 11,	14 40,	$p = 59{\cdot}6$ (2);	14 45,	$s = 70{\cdot}57$	(2)	Hall.
16,	11 42,	. . . . .		$s = 77{\cdot}6$	(1)	Hall.
	13 7,	$p = 71{\cdot}9$ (2);		$s = 80{\cdot}83$	(4)	Hall.
	13 36,	. . . . .		$s = 80{\cdot}4$	(1)	Hall.
17,	16 2,	$p = 85{\cdot}5$ (2);	16 19,	$s = 63{\cdot}24$	(3)	Hall.
18,	10 28,	$p = 251{\cdot}7$ (3);	10 18,	$s = 82{\cdot}93$	(8)	Newcomb.
	10 57,	$p = 244{\cdot}5$ (1);	11 5,	$s = 81{\cdot}6$	(1)	Harkness.
	11 50,	$p = 246{\cdot}6$ (4);	11 57,	$s = 81{\cdot}77$	(4)	Hall.
	14 32,	$p = 232{\cdot}1$ (4);	14 39,	$s = 61{\cdot}04$	(4)	Hall.
19,	11 42,	$p = 283{\cdot}2$ (2);	11 49,	$s = 46{\cdot}20$	(4)	Hall.
	15 43,	$p = 255{\cdot}4$ (4);	15 52,	$s = 81{\cdot}37$	(6)	Hall.
20,	10 28,	$p = 61{\cdot}1$ (3);	10 33,	$s = 76{\cdot}07$	(2)	Hall.
	11 57,	$p = 52{\cdot}1$ (4);	12 7,	$s = 59{\cdot}93$	(4)	Hall.

The Second Satellite.

1877, Aug. 17,	16 6,	$p = 73{\cdot}0$ (2);	16 21,	$s = 30{\cdot}81$	(4)	Hall.
18,	11 31,	$p = 248{\cdot}8$ (2);	11 37,	$s = 34{\cdot}65$	(4)	Hall.
19,	11 25,	$p = 226{\cdot}8$ (2);	11 30,	$s = 24{\cdot}08$	(2)	Hall.
20,	13 15,	$p = 67{\cdot}1$ (1);	13 26,	$s = 31{\cdot}95$	(3)	Hall.
	13 56,	. . . . .		$s = 27{\cdot}02$	(4)	Hall.
	14 22,	$p = 70$ (est.);	14 22,	$s = 19{\cdot}16$	(3)	Hall.
	16 19,	$p = 250$ (est.);	16 19,	$s = 15{\cdot}15$	(7)	Hall.
	16 35,	. . . . .		$s = 16{\cdot}70$	(7)	Hall.

From these observations Professor Newcomb has derived the following approximate circular elements of the orbits. The probable errors assigned are only very rough estimates.

The Outer Satellite.

Major semi-axis of apparent orbit seen at distance [9·5930] .	$82''{\cdot}5 \pm 0''{\cdot}5$
Minor semi-axis of apparent orbit seen at distance [9·5930] .	$27''{\cdot}7 \pm 2''$.
Major semi-axis of orbit seen at distance unity . . .	$32''{\cdot}3$
Position-angles of apsides of apparent orbit	$70°$, $250° \pm 2°$
Passage through the west apsis ($p = 250°$), Aug. 19, $16^h{\cdot}6$, W.M.T.	
Period of revolution	$30^h\ 14^m \pm 2^m$
Hourly motion in Areocentric longitude	$11°{\cdot}907$
Inclination of true orbit to the ecliptic	$25°{\cdot}4 \pm 2$
Longitude of ascending node	$82°{\cdot}8 \pm 3$

Position of pole of orbit in celestial sphere .	Long.	352·8
	Lat.	+ 64·6
	R.A.	316·1
	Decl.	+ 53·8

These elements give for the Mass of *Mars* . $\frac{1}{3{,}090{,}000}$

The Inner Satellite.

Major semi-axis of apparent orbit at distance [9·5930] .	$33''{\cdot}0 \pm 1''$
Period of revolution	$7^{h}\ 38^{m}{\cdot}5 \pm 0^{m}{\cdot}5$
Hourly motion in Areocentric longitude	$47°{\cdot}11$

Passage through the eastern apsis ($p = 70°$) Aug. 20, $13^{h}{\cdot}0$, W.M.T.

Very respectfully, your obedient servant,

JOHN RODGERS,

Rear Admiral and Superintendent.

The Hon. R. W. Thompson, Secretary of the Navy.

On the Solution of Kepler's Problem.

By J. W. L. Glaisher, M.A., F.R.S.

§ 1. Writing Kepler's equation in the form

$$x = a + e \sin x, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

the solution in powers of e is

$$x = a + e \sin a + \frac{e^2}{1.2}\frac{d}{da}(\sin^2 a) + \frac{e^3}{1.2.3}\frac{d^2}{da^2}(\sin^3 a) + \&c.,$$

and, on performing the differentiations, it will be found that

$$\begin{aligned} x = {} & a \\ & + e . \sin a \\ & + e^2 . \sin a \cos a \\ & + e^3 . \sin a \cos^2 a - \frac{1}{2} \sin^3 a \\ & + e^4 . \sin a \cos^3 a - \frac{5}{3} \sin^3 a \cos a \\ & + e^5 . \sin a \cos^4 a - \frac{11}{3} \sin^3 a \cos^2 a + \frac{13}{24} \sin^5 a \\ & + e^6 . \sin a \cos^5 a - \frac{20}{3} \sin^3 a \cos^3 a + \frac{47}{15} \sin^5 a \cos a \\ & + e^7 . \sin a \cos^6 a - \frac{65}{6} \sin^3 a \cos^4 a + \frac{1291}{120} \sin^5 a \cos^2 a - \frac{541}{720} \sin^7 a \\ & + e^8 . \sin a \cos^7 a - \frac{49}{3} \sin^3 a \cos^5 a + \frac{427}{15} \sin^5 a \cos^3 a - \frac{1957}{315} \sin^7 a \cos a \\ & + \&c. \end{aligned} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Thus, as is well known, the expression

$$a+\frac{e\sin a}{1-e\cos a} \quad \ldots\ldots\ldots \quad (3)$$

differs from the root of the equation (1) only by quantities of the order e^3. It is also to be noticed that the second term of (3) represents the sum of the terms contained in the first column of (2), continued to infinity.

It is evident, therefore, that if the value of the series (2) had to be calculated up to the terms of the fourth or a higher order, it would be preferable to calculate the value of the second term in (3) rather than the values of the terms in the first column of (2), so that, in the calculation of the terms in the other columns, we may assume that the value of $\log(1-e\cos a)$ has been already obtained; and it is of some interest to examine whether these terms can be arranged in such a manner that the knowledge of the value of $\log(1-e\cos a)$ may be applied to reduce the number of logarithmic entries required for their calculation.

§ 2. It is clear that the terms in e^3 and e^4 in the second column of (2) can be represented by

$$-\frac{1}{2}\frac{e^3\sin^3 a}{(1-e\cos a)^{\frac{10}{3}}},$$

so that

$$a+\frac{e\sin a}{1-e\cos a}-\frac{1}{2}\frac{e^3\sin^3 a}{(1-e\cos a)^{\frac{10}{3}}} \quad \ldots\ldots \quad (4)$$

differs from the root of (1) only by quantities of the order e^5: in fact we find that

$$\begin{aligned} x = a &+\frac{e\sin a}{1-e\cos a}-\frac{1}{2}\frac{e^3\sin^3 a}{(1-e\cos a)^{\frac{10}{3}}} \\ &+e^5.-\frac{1}{18}\sin^3 a\cos^2 a+\frac{13}{24}\sin^5 a \\ &+e^6.-\frac{20}{81}\sin^3 a\cos^3 a+\frac{47}{15}\sin^5 a\cos a \\ &+e^7.-\frac{325}{162}\sin^3 a\cos^4 a+\frac{1291}{120}\sin^5 a\cos^2 a-\frac{541}{720}\sin^7 a \\ &+e^8.-\frac{1039}{729}\sin^3 a\cos^5 a+\frac{427}{15}\sin^5 a\cos^3 a-\frac{1957}{315}\sin^7 a\cos a \\ &+\&c. \qquad \ldots\ldots \quad (5) \end{aligned}$$

§ 3. The terms involving e^5 and e^6 in (5)

$$= e^5 . -\frac{1}{18}\sin^3 a \quad + \frac{43}{72}\sin^5 a$$

$$+ e^6 . -\frac{20}{81}\sin^3 a \cos a + \frac{1369}{405}\sin^5 a \cos a,$$

$$= e^5 . -\frac{1}{18}(1 + \frac{40}{9} e \cos a)\sin^3 a$$

$$+ e^5 . \frac{43}{72}(1 + \frac{10952}{1935} e \cos a)\sin^5 a;$$

so that these terms may be represented by

$$-\frac{1}{18}\frac{e^5 \sin^3 a}{(1-e\cos a)^{\frac{40}{9}}} + \frac{43}{72}\frac{e^5 \sin^5 a}{(1-e\cos a)^{\frac{10952}{1935}}} . \quad . \quad . \quad (6)$$

If the exponent $\frac{10952}{1935}$ be replaced by $\frac{17}{3}$, the first two terms of the expanded value are

$$\frac{43}{72} e^5 \sin^5 a (1 + \frac{10965}{1935} e \cos a),$$

which differs from the quantity to be represented by only

$$\frac{13}{3240} e^6 \sin^5 a \cos a = \frac{1}{249} e^6 \sin^5 a \cos a, \text{ nearly.}$$

Thus the expression

$$a + A,$$

where

$$A = \frac{e \sin a}{1-e\cos a} - \frac{1}{2}\frac{e^3 \sin^3 a}{(1-e\cos a)^{\frac{19}{9}}} - \frac{1}{18}\frac{e^5 \sin^3 a}{(1-e\cos a)^{\frac{40}{9}}} + \frac{43}{72}\frac{e^5 \sin^5 a}{(1-e\cos a)^{\frac{17}{3}}} \quad (7)$$

differs from the root of the equation (1) by

$$\frac{13}{3240} e^6 \sin^5 a \cos a + \text{terms of the seventh and higher orders,}$$

so that practically (7) gives the solution of Kepler's problem to the sixth order inclusive.

§ 4. Supposing the values of log e, log sin a, and log cos a to be given (in addition, of course, to the logarithms of the coefficients, which are assumed to be known), the calculation from (2) as it stands, up to the sixth order inclusive, would require twelve entries of the table of logarithms, while the calculation of log $(1 - e \cos a)$ requires two entries, and that of the terms in A four more, so that by the use of A six entries are saved. If log $(1 - e \cos a)$ be calculated and used in obtaining the first column of (2), the other terms in (2) require six entries, making nine in all, so that three are saved by the use of the last three terms of A. The calculation, of the expression (4), which

gives the value of the root up to the fourth order inclusive, requires four entries, while the calculation from (2) requires six entries if the values of the separate terms in the first column are obtained, and five entries if they are replaced by

$$\frac{e \sin a}{1 - e \cos a}.$$

§ 5. On developing the expression A up to the seventh order, it is found to be

$$\begin{aligned}
&= e \cdot \sin a \\
&+ e^2 \cdot \sin a \cos a \\
&+ e^3 \cdot \sin a \cos^2 a - \frac{1}{2} \sin^3 a \\
&+ e^4 \cdot \sin a \cos^3 a - \frac{5}{3} \sin^3 a \cos a \\
&+ e^5 \cdot \sin a \cos^4 a - \frac{65}{18} \sin^3 a \cos^2 a - \frac{1}{18} \sin^3 a + \frac{43}{72} \sin^5 a \\
&+ e^6 \cdot \sin a \cos^5 a - \frac{520}{81} \sin^3 a \cos^3 a - \frac{20}{81} \sin^3 a \cos a + \frac{731}{216} \sin^5 a \cos a \\
&+ e^7 \cdot \sin a \cos^6 a - \frac{2470}{243} \sin^3 a \cos^4 a - \frac{490}{729} \sin^3 a \cos^2 a + \frac{3655}{324} \sin^5 a \cos^2 a \\
&+ \&c.
\end{aligned}$$

$$\begin{aligned}
&= e \cdot \sin a \\
&+ e^2 \cdot \sin a \cos a \\
&+ e^3 \cdot \sin a \cos^2 a - \frac{1}{2} \sin^3 a \\
&+ e^4 \cdot \sin a \cos^3 a - \frac{5}{3} \sin^3 a \cos a \\
&+ e^5 \cdot \sin a \cos^4 a - \frac{11}{3} \sin^3 a \cos^2 a + \frac{13}{24} \sin^5 a \\
&+ e^6 \cdot \sin a \cos^5 a - \frac{20}{3} \sin^3 a \cos^3 a + \frac{2033}{648} \sin^5 a \cos a \\
&+ e^7 \cdot \sin a \cos^6 a - \frac{7900}{729} \sin^3 a \cos^4 a + \frac{30935}{2916} \sin^5 a \cos^2 a \\
&+ \&c.
\end{aligned}$$

Subtracting this from (2), it appears that the correction to be *added* to A to give the true value of the root of the equation (1) is

$$\begin{aligned}
&e^6 \cdot -\frac{13}{3240} \sin^5 a \cos a \\
&+ e^7 \cdot \frac{5}{1458} \sin^3 a \cos^4 a + \frac{4363}{29160} \sin^5 a \cos^2 a - \frac{541}{720} \sin^7 a \\
&+ \&c.,
\end{aligned}$$

which very nearly

$$= e^6 . -\frac{1}{249} \sin^5 a \cos a$$

$$+ e^7 . \quad \frac{1}{292} \sin^3 a \cos^4 a + \frac{3}{20} \sin^5 a \cos^2 a - \frac{3}{4} \sin^7 a$$

$$+ \&c., \qquad \ldots\ldots (8)$$

The smallness of the coefficients of the terms of the seventh order in (8) compared with those in (2) is worthy of remark: the sum of the first three coefficients in the e^7 line in (2) is equal to about 23 and in (8) to less than unity.

It is noticeable also how nearly the expression

$$-\frac{1}{2} \frac{e^3 \sin^3 a}{(1 - e \cos a)^{\frac{10}{3}}}$$

represents the first *three* terms of the second column of (2), the coefficient of the third term differing from $\frac{11}{3}$ by only $\frac{1}{18}$. The quantity to be added to the expression in (4) to give the value of the root up to the fifth order inclusive is

$$e^5 . -\frac{1}{18} \sin^3 a + \frac{43}{72} \sin^5 a,$$

which

$$= e^5 . -\frac{1}{18} \sin^3 a + \frac{3}{5} \sin^5 a, \text{ nearly,}$$

since

$$\frac{3}{5} - \frac{43}{72} = \frac{1}{360}.$$

§6. The numbers within square brackets denoting the Briggian logarithms of the coefficients expressed in seconds, the value of A is

$$[5{\cdot}3144251] \frac{e \sin a}{1 - e \cos a} - [5{\cdot}0133951] \frac{e^3 \sin^3 a}{(1 - e \cos a)^{\frac{10}{3}}} - [4{\cdot}0591526] \frac{e^5 \sin^3 a}{(1 - e \cos a)^{\frac{40}{9}}}$$

$$+ [5{\cdot}0905611] \frac{e^5 \sin^5 a}{(1 - e \cos a)^{\frac{17}{3}}}.$$

As an example of the application of this formula, let $a = \frac{1}{4}$ and $e = 50°$, this being the example considered on pp. 376, 377 of this volume.

The work is then as follows, every figure that has to be written down being printed:—

$\log e = 9{\cdot}3979400$ $\log \cos a = 9{\cdot}8080675$

$\log e^3 = 8{\cdot}1938200$ $\log \sin a = 9{\cdot}8842540$

$\log e^5 = 6{\cdot}9897000$ $\log \sin^3 a = 9{\cdot}6527620$

$\log \sin^5 a = 9{\cdot}4212700$

$\log e$	$9{\cdot}3979400$
$\log \cos a$	$9{\cdot}8080675$
	$9{\cdot}2060075$
$e \cos a$	$0{\cdot}1606969$
$1 - e \cos a$	$0{\cdot}8393031$
$\log (1 - e \cos a)$	$9{\cdot}9239189$
Ar. Co.	$0{\cdot}0760811$ = log P, say,
	$0{\cdot}008453456$ = log $P^{\frac{1}{9}}$
	$0{\cdot}25360368$ = log $P^{\frac{3}{9}}$ = log $P^{\frac{1}{3}}$
	$0{\cdot}33813824$ = log $P^{\frac{4}{9}}$
	$0{\cdot}42267280$ = log $P^{\frac{5}{9}}$
	$0{\cdot}43112626$ = log $P^{\frac{47}{9}}$ = log $P^{\frac{17}{3}}$

(+)	(−)	(−)	(+)
$5{\cdot}3144251$	$5{\cdot}0133951$	$4{\cdot}05915$	$5{\cdot}09056$
$9{\cdot}3979400$	$8{\cdot}1938200$	$6{\cdot}98970$	$6{\cdot}98970$
$9{\cdot}8842540$	$9{\cdot}6527620$	$9{\cdot}65276$	$9{\cdot}42127$
$0{\cdot}0760811$	$0{\cdot}2536037$	$0{\cdot}33814$	$0{\cdot}43113$
$4{\cdot}6727002$	$3{\cdot}1135808$	$1{\cdot}03975$	$1{\cdot}93266$
″	″	″	″
$47065{\cdot}23$	$1298{\cdot}91$	$10{\cdot}96$	$85{\cdot}64$
$85{\cdot}64$	$10{\cdot}96$		
$47150{\cdot}87$	$1309{\cdot}87$		
$1309{\cdot}87$			

$45841{\cdot}00 = 12^\circ\ 44'\ 1''{\cdot}00$;

thus $A = 12^\circ\ 44'\ 1''{\cdot}00$, and

$$x = a + A, = 62^\circ\ 44'\ 1''{\cdot}00, \quad \ldots\ldots \quad (9)$$

the true value being (see p. 377) $62^\circ\ 43'\ 56''{\cdot}00$.

The value of the expression in (4), that is of a + the first two terms of A, $= 62^\circ\ 42'\ 46''$, and the correction for terms of the fifth order, viz.:

$$e^5 . -\frac{1}{18}\sin^3 a + \frac{3}{5}\sin^5 a$$

$= -5''{\cdot}03 + 31''{\cdot}88$, giving $x = 62^\circ\ 43'\ 13''$.

§7. The correction to be applied to (7) in order to include approximately the terms of the seventh order, viz.:

$$e^7.\frac{3}{20}\sin^5 a-\frac{9}{10}\sin^7 a$$

$=0''\cdot50-1''\cdot75=-1''\cdot25$. As the error of (9) is about $5''$, it will be seen that, the seventh order correction just obtained being very small, there is very little advantage in including these terms. In general, the classification of the terms according to orders of e supposes that e is very small; so small, in fact, that a term involving e^{n+1} may be regarded as distinctly smaller than one involving e^n: but if e be as large as $\frac{1}{4}$, the terms of the orders near to e^8 do not differ much from one another in magnitude, in consequence of the increased values of the coefficients, which somewhat counteract the effect of the additional factor e. This is readily seen by considering the terms in e^8. By expanding the terms in A, it will be found that the terms in e^8, omitting the first, are

$$=-14\cdot90809\sin^3 a\cos^5 a-1\cdot44389\sin^3 a\cos^3 a+28\cdot82887\sin^5 a\cos^3 a$$

$$=-16\cdot35198\sin^3 a\cos^5 a+27\cdot38498\sin^5 a\cos^3 a \quad \ldots\ldots\ldots (10)$$

(in which the coefficients are expressed as decimals so that their magnitudes may be more evident): the terms in e^8 in (2), omitting the first, are

$$=-16\cdot33333\sin^3 a\cos^5 a+28\cdot46667\sin^5 a\cos^3 a-6\cdot21270\sin^7 a\cos a \quad \ldots\ldots (11)$$

and the difference

$$=e^8.0\cdot01865\sin^3 a\cos^5 a+1\cdot08169\sin^5 a\cos^3 a-6\cdot21270\sin^7 a\cos a:$$

in the case of $e=\frac{1}{4}$, this difference $=0''\cdot00+0''\cdot24-1''\cdot95$ $=-1''\cdot71$.

The close agreement between the coefficients of $\sin^3 a\cos^5 a$ and $\sin^5 a\cos^3 a$ in (10) and (11) is remarkable; and it will be noted that the coefficient of the new term, viz. the term in $\sin^7 a\cos a$, is, as in the case of the terms of the seventh order, much the largest.

It thus appears that if e be so large that, in order to obtain the value of x to the nearest tenth or hundredth of a second, terms of a higher order than the sixth have to be included, in general no great additional accuracy will be obtained by applying to A the corrections for the terms of the seventh and eighth orders, while of course if the terms in e^7 may be neglected, the corrections are insensible. Whenever, therefore, the series in (2) affords a suitable solution of the problem, the expression $a+\mathrm{A}$ gives the solution up to the seventh order, and in general but little additional accuracy is gained by applying the corrections

for the seventh and higher orders. The advantage of using the formula $a+\mathrm{A}$ would be greatest if e were very small, so that the order of e governed the magnitude of each term, and if the value of x were required with great exactness; as, for example, if the accuracy required were such that ten-figure logarithms had to be employed in the calculation of the first term of A, but that terms above e^7 were insensible.

The following are the values of the terms in (2), for this case of $e=\frac{1}{4}$, $a=50°$, up to the sixth order inclusive :—

$$\begin{aligned} x &= 50° \\ &\quad + 39502''{\cdot}00 \\ &\quad + 6347''{\cdot}85 \\ &\quad + 1020''{\cdot}08 - 724''{\cdot}40 \\ &\quad + 163''{\cdot}92 - 388''{\cdot}03 \\ &\quad + 26''{\cdot}34 - 137''{\cdot}18 + 28''{\cdot}78 \\ &\quad + 4''{\cdot}23 - 40''{\cdot}08 + 26''{\cdot}76 \\ &= 50° + 45830''{\cdot}27 = 62°\ 43'\ 50''{\cdot}27; \end{aligned}$$

the terms in e^7

$$\begin{aligned} &= +0''{\cdot}68 - 10''{\cdot}47 + 14''{\cdot}76 - 1''{\cdot}46 \\ &= 3''{\cdot}51; \end{aligned}$$

and the terms in e^8

$$\begin{aligned} &= 0''{\cdot}11 - 2''{\cdot}54 + 6''{\cdot}28 - 1''{\cdot}95 \\ &= 1''{\cdot}90; \end{aligned}$$

so that, when the seventh order terms are included, the value is $62°\ 43'\ 53''{\cdot}78$; and when the terms of the eighth order are also included, $62°\ 43'\ 55''{\cdot}68$.

§ 8. As another example, let $e=\frac{1}{10}$, $a=50°$, and the terms of A

$$= 16886''{\cdot}23 - 57''{\cdot}85 - 0''{\cdot}07 + 0''{\cdot}47,$$

so that $a+\mathrm{A}=54°\ 40'\ 28''{\cdot}78$, which will be found to satisfy the equation to within the hundredth of a second.

§ 9. The exponents in the denominators of the terms in A are $\frac{30}{9}$, $\frac{40}{9}$, $\frac{51}{9}$; if the last exponent be taken to be $\frac{50}{9}$, the sixth order error

$$= +\frac{101}{1620}e^6 \sin^5 a \cos a, \quad = +\frac{1}{16}e^6 \sin^5 a \cos a, \text{ nearly,}$$

and is thus much larger than when the exponent is $\frac{51}{9}$, the error in this case (*see* § 3) being

$$= -\frac{1}{249}e^6 \sin^5 a \cos a, \text{ nearly.}$$

§ 10. If the terms in (2) be treated in columns as in §§ 2 and 3, each column being kept distinct, it will be found that up to the sixth order inclusive,

$$x = a + \frac{e \sin a}{1 - e \cos a} - \frac{1}{2} \frac{e^3 \sin^3 a}{(1 - e \cos a)^{\frac{10}{3}}} - \frac{1}{18} \frac{e^5 \sin^3 a \cos^2 a}{(1 - e \cos a)^{\frac{40}{3}}} + \frac{13}{24} \frac{e^5 \sin^5 a}{(1 - e \cos a)^{\frac{37}{6}}},$$

so that

$$x = a + \mathrm{B},$$

where

$$\mathrm{B} = \frac{e \sin a}{1 - e \cos a} - \frac{1}{2} \frac{e^3 \sin^3 a}{(1 - e \cos a)^{\frac{10}{3}}} - \frac{1}{18} \frac{e^5 \sin^3 a \cos^2 a}{(1 - e \cos a)^{\frac{40}{3}}} + \frac{13}{24} \frac{e^5 \sin^5 a}{(1 - e \cos a)^{\frac{23}{4}}},$$

the correction to be added to B being

$$e^6 . \frac{9}{480} \sin^5 a \cos a$$

$$+ e^7 . \frac{5}{1458} \sin^3 a \cos^4 a + \frac{947}{3840} \sin^5 a \cos^2 a - \frac{541}{720} \sin^7 a$$

$$+ \&c.,$$

which, very nearly,

$$= e^6 . \frac{1}{53} \sin^5 a \cos a$$

$$+ e^7 . \frac{1}{292} \sin^3 a \cos^4 a + \frac{1}{4} \sin^5 a - \sin^7 a$$

$$+ \&c.$$

It is clear that the expression B is not so convenient for calculation as A; and also the residual sixth order term is larger for B than for A.

§ 11. In t. v. (1859) of the *Annales de l'Observatoire de Paris*, pp. 349, 350,* M. Serret gives an account of a method, indicated by M. Leverrier on p. 192 of t. i., of solving Kepler's problem by means of a series of a different form to (2). The method is as follows:—

Let x_0 be an approximate value of x, and put

$$v = a - x_0 + e \sin x_0;$$

then

$$x - e \sin x = x_0 - e \sin x_0 + v.$$

This is the equation to be solved, and we can calculate x by

* "Note sur l'équation dont dépend l'anomalie excentrique, et sur les séries qui se présentent dans la théorie du mouvement elliptique des corps célestes."

developing it in ascending powers of v by Maclaurin's theorem; we have

$$(1-e\cos x)\frac{dx}{dv}=1,$$

$$(1-e\cos x)\frac{d^2x}{dv^2}+e\sin x\left(\frac{dx}{dv}\right)^2=0,$$

$$(1-e\cos x)\frac{d^3x}{dv^3}+3e\sin x\frac{dx}{dv}\frac{d^2x}{dv^2}+e\cos x\left(\frac{dx}{dv}\right)^3=0,$$

&c. &c.

When $v=0$, $x=x_0$, and

$$\frac{dx}{dv}=\frac{1}{1-e\cos x_0},\quad \frac{d^2x}{dv^2}=-\frac{e\sin x_0}{(1-e\cos x_0)^3},$$

$$\frac{d^3x}{dv^3}=\frac{3e^2\sin^2 x_0}{(1-e\cos x_0)^5}-\frac{e\cos x_0}{(1-e\cos x_0)^4},$$

whence

$$x=x_0+\frac{1}{1-e\cos x_0}v-\frac{1}{2}\frac{e\sin x_0}{(1-e\cos x_0)^3}v^2$$
$$+\left\{\frac{1}{2}\frac{e^2\sin^2 x_0}{(1-e\cos x_0)^5}-\frac{1}{6}\frac{e\cos x_0}{(1-e\cos x_0)^4}\right\}v^3+\&c.,\quad\ldots\ldots\quad(12)$$

In the case of an orbit in which e is very small, put $x_0=a$, then $v=e\sin a$ and, neglecting terms of the fourth order,

$$x=a+\frac{e\sin a}{1-e\cos a}-\frac{1}{2}\left(\frac{e\sin a}{1-e\cos a}\right)^3.\quad\ldots\ldots\quad(13)$$

M. Serret remarks that this formula is very convenient for calculation, and that the last term can be immediately derived from the previous term.

§ 12. It will be found that the coefficient of v^4 in (12) is

$$-\frac{5}{8}\frac{e^3\sin^3 x_0}{(1-e\cos x_0)^7}+\frac{5}{12}\frac{e^2\sin x_0\cos x_0}{(1-e\cos x_0)^6}+\frac{e\sin x_0}{(1-e\cos x_0)^5};$$

and therefore, putting $x_0=a$, the formula, whose first three terms are given by M. Serret's equation (13), is

$$x=a+\frac{e\sin a}{1-e\cos a}-\frac{1}{2}\frac{e^3\sin^3 a}{(1-e\cos a)^3}$$
$$+\frac{1}{2}\frac{e^5\sin^5 a}{(1-e\cos a)^5}-\frac{1}{6}\frac{e^4\sin^3 a\cos a}{(1-e\cos a)^4}$$
$$-\frac{5}{8}\frac{e^7\sin^7 a}{(1-e\cos a)^7}+\frac{5}{12}\frac{e^6\sin^5 a\cos a}{(1-e\cos a)^6}+\frac{1}{24}\frac{e^5\sin^5 a}{(1-e\cos a)^5}$$
$$+\&c.;\quad\ldots\ldots\quad(14$$

the second line being derived from the terms in v^2, and the third from those in v^3.

In the case of $e = \frac{1}{4}$, $a = 50°$, this gives

$$x = 50° + 47065''{\cdot}23 - 1225''{\cdot}24$$
$$+ \quad 63''{\cdot}79 - \quad 78''{\cdot}20$$
$$- \quad 4''{\cdot}15 + \quad 9''{\cdot}16 + 5''{\cdot}32$$
$$+ \&c.$$

		°	′	″
The first line	=	52	43	59·99
the second line	= −			14·41
the third line	= +			10·33
		52	43	55·91

The close approximation afforded by the first line (the error is only $3''{\cdot}99$) is very remarkable, but it is of course accidental; the term of the fourth order $= 78''{\cdot}20$, and those of the fifth order amount to $69''{\cdot}11$.

§ 13. The formula (13), which is true to the third order, only differs from (4), which is true to the fourth order, in the exponent of the denominator, which is $\frac{10}{3}$ instead of 3. If $e = \frac{1}{10}$, $a = 50°$, the last term of (13) $= 56''{\cdot}59$; and the value of x from (13) is $54°\ 40'\ 29''{\cdot}64$, and from (4) is $54°\ 40'\ 28''{\cdot}38$, the true value as found in § 8 being $54°\ 40'\ 28''{\cdot}78$.

As another example, let $e = \frac{1}{7}$, a being, as before, 50°, then (14) gives

$$x = 50° + 24854''{\cdot}92 - 180''{\cdot}45$$
$$+ \quad 2''{\cdot}62 - \quad 6''{\cdot}08$$
$$- \quad 0''{\cdot}05 + \quad 0''{\cdot}22 + 0''{\cdot}22$$
$$+ \&c.;$$

the first line $= 56°\ 51'\ 14''{\cdot}47$, the second $- 3''{\cdot}46$, and the third $0''{\cdot}39$, leading to $x = 56°\ 51'\ 11''{\cdot}40$; and the true value obtained by substituting this in (1) is $56°\ 51'\ 11''{\cdot}39$.

The value of $a + \mathrm{A}$ is

$$50° + 24854''{\cdot}92 - 186''{\cdot}34 - 0''{\cdot}47 + 3''{\cdot}34,$$

which $= 56°\ 51'\ 11''{\cdot}45$.

The value obtained from (4) is $56°\ 51'\ 8''{\cdot}58$.

§ 14. It will be noticed that in both these examples the formula (13) affords a very close approximation to the true value; this is due to the fact that the terms in the second line of (14) nearly counteract one another for the values of e and a that have been taken; for, these terms

$$= \frac{1}{2} \frac{e^4 \sin^3 a}{(1 - e \cos a)^4} \{e \sin^2 a - \frac{1}{3} \cos a\},$$

and the term in brackets is small for the assumed values of e and a. As an example in which this is not the case, let $e = \frac{1}{4}$, $a = 130°$, then (14) gives

$$\begin{aligned} &130° + 34032''{\cdot}99 - 463''{\cdot}25 \\ &\quad + \quad 12''{\cdot}61 + \ 21''{\cdot}38 \\ &\quad - \quad 0''{\cdot}43 - \ 1''{\cdot}46 + 1''{\cdot}05. \end{aligned}$$

The first line $= 139°\ 19'\ 29''{\cdot}74$, the second $33''{\cdot}99$, and the third $-0''{\cdot}84$, leading to $x = 139°\ 20'\ 2''{\cdot}89$.

The value of $a + \mathrm{A}$

$$\begin{aligned} &= 130° + 34032''{\cdot}99 - 440''{\cdot}81 - 2''{\cdot}59 + 13''{\cdot}64 \\ &= 139°\ 20'\ 3''{\cdot}23. \end{aligned}$$

The value of x given by (4) is $139°\ 19'\ 52''{\cdot}18$, which only differs from the true result (viz. $139°\ 20'\ 2''{\cdot}93$) by about $11''$. It is evident that the effect of the denominators in (7) and (14) is to increase the magnitudes of the terms if a be in the first or fourth quadrants, and diminish them if a be in the second or third quadrants.

The expression in (4) is only very slightly more complicated than (13), and as it represents the root to one order higher, it is in general to be preferred.

§ 15. The series in (14) is clearly the expansion of x in powers of $\frac{e}{1 - e\cos a}$, and it may therefore be obtained directly in the following manner:—

Let

$$\epsilon = \frac{e}{1 - e\cos a},$$

then

$$e = \frac{\epsilon}{1 + \epsilon\cos a};$$

the equation is

$$x = a + \frac{\epsilon}{1 + \epsilon\cos a}\sin x,$$

viz.

$$x = a + \epsilon\,(\sin x - x\cos a + a\cos a),$$

and therefore, by Lagrange's theorem,

$$x = a + \epsilon\sin a + \frac{\epsilon^2}{1.2}\frac{d}{dx}(\sin x - x\cos a + a\cos a)^2 + \frac{\epsilon^3}{1.2.3}\frac{d^2}{dx^2}(\sin x - x\cos a + a\cos a)^3 + \&c., \quad . \ . \ . \quad (15)$$

x being put equal to a after the differentiations have been performed; thus

$$\begin{aligned} x = \quad & a \\ & + \epsilon \,.\, \sin a \\ & + \epsilon^2 \,.\, -\frac{1}{2} \sin^3 a \\ & + \epsilon^4 \,.\, -\frac{1}{6} \sin^3 a \cos a \\ & + \&c. \end{aligned}$$

It is evident that there will be no terms in the expansion involving powers of $a \cos a$, for

$$\sin x - x \cos a + a \cos a = \sin a, \text{ when } x = a,$$

and its differential coefficient $= \cos x - \cos a$. When $x = a$ this vanishes, and the terms are in consequence greatly simplified: in fact, the development of (15) may be very rapidly effected.

§ 16. A similar method affords the expansion of x in powers of $\frac{e}{1 + e \cos a}$; for, let

$$\eta = \frac{e}{1 + e \cos a},$$

then

$$x = a + \frac{\eta}{1 - \eta \cos a} \sin x,$$

viz.

$$x = a + \eta (\sin x + x \cos a - a \cos a),$$

and therefore

$$\begin{aligned} x = a + \eta \sin a + & \frac{\eta^2}{1.2} \frac{d}{dx} (\sin x + x \cos a - a \cos a)^2 \\ & + \frac{\eta^3}{1.2.3} \frac{d^2}{dx^2} (\sin x + x \cos a - a \cos a)^3 + \&c., \end{aligned}$$

x being put equal to a.

We thus find

$$\begin{aligned} x = \quad & a \\ & + \eta \,.\, \sin a \\ & + \eta^2 \,.\, 2 \sin a \cos a \\ & + \eta^3 \,.\, 4 \sin a \cos^2 a - \frac{1}{2} \sin^3 a \\ & + \eta^4 \,.\, 8 \sin a \cos^3 a - \frac{19}{6} \sin^3 a \cos a \\ & + \eta^5 \,.\, 16 \sin a \cos^4 a - \frac{40}{3} \sin^3 a \cos^2 a + \frac{13}{24} \sin^5 a \\ & + \&c. \end{aligned}$$

The first column evidently

$$= a + \frac{\eta \sin a}{1 - 2\eta \cos a}, = a + \frac{e \sin a}{1 - e \cos a}.$$

§ 17. I here add another solution of Kepler's problem in series, the denominators of the terms being powers of $1 - e \cos a$.

If

$$x = a + efx$$

then, by Lagrange's theorem,

$$Fx = Fa + efaF'a + \frac{e^2}{1.2}\frac{d}{da} f^2 aF'a + \frac{e^3}{1.2.3}\frac{d^2}{da^2} f^3 aF'a + \&c.$$

Now let

$$Fx = \frac{1}{1 - ef'x} = \frac{dx}{da},$$

therefore

$$\frac{dx}{da} = \frac{1}{1 - ef'a} + \frac{e^2 faf'a}{(1 - ef'a)^2} + \frac{e^3}{1.2}\frac{d}{da}\frac{f^2 af''a}{(1 - ef'a)^2} + \frac{e^4}{1.2.3}\frac{d^2}{da^2}\frac{f^3 af''a}{(1 - ef'a)^2} + \&c.$$

$$= 1 + \frac{ef'a}{1 - ef'a} + \frac{e^2 faf''a}{(1 - ef'a)^2} + \frac{e^3}{1.2}\frac{d}{da}\frac{f^2 af''a}{(1 - ef'a)^2} + \&c.;$$

whence, integrating,

$$x = a + \frac{efa}{1 - ef'a} + \frac{e^3}{1.2}\frac{f^2 af''a}{(1 - ef'a)^2} + \frac{e^4}{1.2.3}\frac{d}{da}\frac{f^3 af''a}{(1 - ef'a)^2} + \&c.$$

In the case of Kepler's problem

$$fa = \sin a, \quad f'a = \cos a, \quad f''a = -\sin a;$$

and therefore

$$x = a + \frac{e \sin a}{1 - e \cos a} - \frac{e^3}{1.2}\frac{\sin^3 a}{(1 - e \cos a)^2} - \frac{e^4}{1.2.3}\frac{d}{da}\frac{\sin^4 a}{(1 - e \cos a)^2}$$

$$- \frac{e^5}{1.2.3.4}\frac{d^2}{da^2}\frac{\sin^5 a}{(1 - e \cos a)^2} - \&c.$$

$$= a + \frac{e \sin a}{1 - e \cos a}$$

$$- \frac{e^3}{2}\frac{\sin^3 a}{(1 - e \cos a)^2}$$

$$- \frac{e^4}{3}\left\{2\frac{\sin^3 a \cos a}{(1 - e \cos a)^2} - \frac{e \sin^5 a}{(1 - e \cos a)^3}\right\},$$

$$- \frac{e^5}{24}\left\{20\frac{\sin^3 a}{(1 - e \cos a)^2} - 25\frac{\sin^5 a}{(1 - e \cos a)^3} - 22\frac{e \sin^5 a \cos a}{(1 - e \cos a)^3} + 6\frac{e^2 \sin^7 a}{(1 - e \cos a)^4}\right\},$$

$$- \&c.$$

1877, *August* 4.

Note on the Arc of Light seen round Venus in Transit.

By R. A. Proctor, Esq.

My attention has been directed to remarks made on this subject after the reading of a paper by Mr. Brett relating to *Venus*. The paper itself I need not refer to. But the remarks upon it have raised hopes in some minds that it may be possible to increase the intrinsic brightness of light from a disk or other visible surface (as distinguished from bodies like the stars, which are reduced appreciably to points by distance). For it was assumed, in the first place, that the arc of light seen round *Venus* in transit (whether she is partly or wholly immersed) is really brighter than the Sun's disk; and it was maintained in the second place, that this superior brightness could be accounted for either by the effects of a refractive atmosphere, or by specular reflexion at the surface of *Venus*. If this were so, it would be easy to produce the same effect artificially. The faint light of planetary disks, of nebulæ, of comets, etc., might be strengthened, and at the same time rendered more suitable for direct spectroscopic observation, by interposing something of the nature of a large thermometer bulb—any opaque globe in fact, within a transparent envelope of suitable refractive qualities. This would be an important gain. Unfortunately there is no reason for hoping that it can ever be attained. The apparently superior brightness of the arc of light seen round *Venus*, or round a thermometer bulb held before a gas flame, or the like, is demonstrably due to two causes, neither implying any real accession of brightness, viz.—first, the effect of contrast against the dark disk within the refracting envelope, secondly and chiefly to the fact that the comparison is made between the light of some less brilliant part of the disk or other surface, and light from the whole disk or surface brought into view by refraction. It will be found on careful trial, if the effect of contrast be removed or greatly diminished (which can readily be done), that under no circumstances does the arc of so-called condensed light exceed or even equal in brilliancy the brightest part of the luminous surface beyond. And this, which is found experimentally to be the case, can readily be shown to be necessarily so. In an article entitled 'Notes on Brightness' in a weekly journal of science, I showed four years ago that by no optical contrivances can apparent brightness be increased, though quantity of light can of course be greatly increased. *Venus* in transit does not differ in this respect from a portion of an enormous optical instrument directed towards the Sun, and the same general reasoning applies to her. It is, however, easily seen, if we take her case specially, that the law holds good. Thus, consider a small strip of the Sun's disk lying on a diameter through *Venus*,—take two points along this strip separated by a distance δr so small that the variation of the amount of refrac-

tion by which rays from points along the arc between these points reach the eye of a terrestrial observer may be considered uniform. Suppose that by the effects of refraction the distance δr, which seen directly from the Earth has that apparent length, is reduced in length, when forming a part of the arc of light round *Venus*, to $\frac{1}{k}\delta r$, k being greater than unity. Then it is obvious that each pencil of rays from points along the luminous strip δr has its divergency in the plane through the strip, *Venus's* centre, and the Earth's, increased, as $k : 1$, in passing along its course (whatever this may be) through the atmosphere of *Venus*. This follows from the uniform variation of the amount of bending for points differently placed along the strip δr. Hence the eye receives fewer rays from each point of the strip δr in the ratio of $1 : k$. Wherefore, neglecting the absorptive effect of *Venus's* atmosphere,

app. brightness of strip δr seen round edge of δ : its app. brightness seen directly

$$:: \frac{\text{light reed. round } \delta \text{ from each pt. of strip}}{\text{apparent area of strip as seen round } \delta} : \frac{\text{light reed. from each pt. of strip directly}}{\text{apparent area of strip seen directly}}$$

$$:: \frac{1}{k} \div \frac{1}{k}\delta r : \frac{1}{\delta r}$$

$$:: 1 : 1,$$

or the brightness is unchanged.

I may take this opportunity of noting that, in a paper on the Nebulæ recently read before the Royal Society, it is asserted that an irresolvable stellar nebula would diminish in apparent brightness (so far as the stellar part of its light is concerned) with increase of distance. No reasoning is given in support of this assertion; and I can see no reason for withdrawing the reasoning by which, in a paper on the Resolvability of Nebulæ regarded as a Test of Distance, I show (incidentally) that a nebula so long as it remained irresolvable would be of constant intrinsic brightness whatever its distance* (always supposing there is no extinction of light in traversing space).

Margate, June 2, 1877.

Absorption of the Light of Venus by Dark Violet Glass Plates.

By Prof. Zenger.

In October 1876 I observed Venus, to detect spots on it, and so look out for the alleged phosphorescent light of the dark part of the disk. I could observe *Venus* early in the morning during nearly the whole of October; it was then very brilliant, casting a shadow, and by its light making it possible to read the maps on the illuminated wall of the observatory. I could even see

* I have since heard that Prof. Stokes, after the paper had been read before the Royal Society, indicated the error into which its writer had fallen in this respect.

the planet with the naked eye at $21^h\ 30^m$ and $21^h\ 40^m$ October 11 and 12, the atmosphere being very calm and pure. On September 30, $20^h\ 12^m$, and the following day, October 1, $17^h\ 15^m$, the disk was admirably defined in the telescope, and there was observed a very brilliant patch near the southern horn some two seconds or less from the terminator in the dark parts of the disk, and this was still visible for two days, when the terminator had passed it, shining like a brilliant star in the surrounding part of the illuminated disk.

This observation induced me to try a new method of photometric measurement by dark violet glass plates, putting one or two between the eye-piece and the eye, and determining the distance at which the light of a lamp vanished by one and then by two plates. I found the proportional intensity to be nearly 1 : 5·6 for one to two. Viewing the planet, it was very striking to observe the great diminution of light on the illuminated disk, as the borders vanished entirely by putting two plates before the eye. I lost sight of nearly one-third of the illuminated part, and the middle of it was with only one plate reduced to nearly one-third of its brilliancy. I therefore concluded that, putting the intensity of the most brilliant part of the planet = 1, and dividing the nearly one-half illuminated part in three parts, the intensities of each were nearly as

$$1 : 1 \div 3 : 1 \div 5{\cdot}6, \text{ that is as } 5{\cdot}6 : 1{\cdot}9 : 1.$$

It is obvious that, using a bi-prism with parallel planes, as for solar eye-pieces, and making one of the prisms of dark violet glass, the other being colourless crown glass, there will be a possibility of applying a scale of intensity by the difference of depth of the violet glass, and of measuring with more accuracy the intensity of such brilliant objects as *Venus*, *Jupiter*, the Moon, &c. It seemed to me to be of interest to communicate these observations, as they confirm the results by a quite different method published in one of the last Numbers of the *Monthly Notices*, and giving a new instance of very highly reflecting points on the surface of *Venus* (perhaps snow-covered high peaks) being visible, like on the Moon, before the solar light reaches the lower parts of the surrounding surface. I could never perceive any trace of the so-termed specular reflection, though I think it would have been perceived if there had been in the middle of the planetary disk such a higher intensity of reflected light in a round or elliptical shape.

The diminution of light in the same longitude from the terminator seemed equal all over the disk of the planet, and not changed under different latitudes, as it should be in case of specular reflection.

P.S.—Though I could detect a faint grayish light, sometimes ruddy near the terminator, during the time from September 30 to October 14, the atmosphere being uncommonly transparent, yet I could never see the whole of the dark part of *Venus*,

though the planet afforded, from 16^h to 18^h in the morning of three days of October, a most splendid view. On the contrary, it seemed with daybreak to be more easy to see the faint illumination near the terminator, even to two-thirds of the whole breadth of the dark part of *Venus*.

Prague, February 17, 1877.

Measures of α Centauri, 1870 to 1877.

By H. C. Russell, Esq., Director of the Sydney Observatory.

As the double star *α Centauri* did not arrive at periastron in 1875 as predicted, perhaps the following measures of this interesting double, taken during the ordinary course of my observations on southern double stars, during the past seven years, may not be without interest. It is evident from these observations that a^2 will not make its nearest approach to a^1 until about the end of this year. Its predicted arrival at that point was therefore nearly three years in error. It is my intention to observe it closely during the next few months; and I hope to obtain such a series of measures as may serve to determine its periastron with accuracy. Some correction may be necessary to my position-angles, on account of *personal bias*, for I find that I do not measure the angle the same when the telescope is east as I do when it is west of the pier (see observations of July 20 and July 24, 1877), but I have not time to investigate the amount before this mail closes.

The observations from 1870 to 1874 were made with a $7\frac{1}{4}$-in. refractor by Merz, of 10 ft. 4 in. focus, and very fine defining power. The remainder have been made with an $11\frac{1}{2}$-in. refractor by Schroeder, a very fine instrument. The method of observing is to place the position-wire bisecting both stars, and then make the distance wires bisect them. After reading, the position-wire is turned right away, and brought back again, and the distance wires crossed; each observation, therefore, which follows is an independent determination of the distance and position-angle. The only exception is the series September 27, 1870, when the position-circle was not moved after it was set the first time.

All the observations, except those in 1870, were taken when the star was near the meridian.

Results of Measures of Double Star α Centauri, at the Sydney Observatory.

Date. 1870	Position-Angle. °	′	Distance. ″	Remarks.
Sept. 27	21	58	10·0	Definition good; stars have sharp round disks; telescope $7\frac{1}{4}$ inches; P. 230; aperture 3 inches.
	21	58	11·0	
	21	58	10·7	
	21	58	10·7	
	21	58	9·6	
Means	21	58	10·40	

Date.	Position-Angle.	Distance.	Remarks.
1870	° ′	″	
Sept. 28	23 24	10·3	Light clouds about; stars very unsteady; telescope $7\frac{1}{4}$; power 150.
	24 17	10·3	
	21 44	10·3	
	21 55	11·0	
Means	22 50	10·47	
Oct. 3	22 5	10·1	Fine clear night; "moonlight"; telescope $7\frac{1}{4}$; power 150.
	22 30	10·4	
	22 11	10·3	
	22 16	10·3	
	22 43	10·2	
Means	22 21	10·26	
Oct. 5	21 40	10·8	Strong wind; much vibration; telescope $7\frac{1}{4}$; power 150.
	21 58	11·0	
	22 28	10·3	
	21 44	10·3	
	22 36	11·1	
Means	22 5	10·70	
1871			
June 3	23 20	10·60	Power 230; telescope $7\frac{1}{4}$.
	21 42	10·31	
	23 13	10·23	
	23 11	10·27	
	22 13	10·05	
	23 49	10·46	
	23 8	10·05	
	22 52	10·03	
	22 33	10·34	
	23 3	10·16	
Means	22 44	10·25	
July 13	22 57	10·05	Stars dancing a good deal; telescope $7\frac{1}{4}$.
	23 15	10·16	
	22 47	9·86	
	23 23	9·82	
	23 5	10·21	
Means	23 5	10·2	

Date.	Position-Angle.	Distance.	Remarks.
1872	° ′	″	
June 7	26 13	9·95	Very thick fog; at times scarcely visible; telescope $7\frac{1}{4}$; power 150.
	25 43	9·82	
	26 3	9·69	
	25 40	9·84	
	25 58	9·73	
	25 48	9·75	
Means	25 54	9·80	
July 5	25 0	9·62	Stopped by clouds; measures good; telescope $7\frac{1}{4}$; power 150.
	24 46	9·75	
	24 30	9·62	
Means	24 45	9·66	
1873			
May 2	28 52	9·45	Stars dancing; aperture of 3 inches; power 333; telescope $7\frac{1}{4}$.
	28 45	9·45	
	27 56	9·66	
	28 17	9·66	
	27 59	9·36	
	28 37	9·40	
Means	28 4	9·50	
1874			
June 13	30 16	7·80	Good definition; measures good; power 140; telescope $7\frac{1}{4}$.
	30 26	7·67	
	29 33	7·76	
	29 21	7·63	
	30 19	7·69	
	30 13	7·84	
	30 6	7·50	
	30 3	7·56	
	30 21	7·76	
	29 29	7·89	
Means	29 59	7·71	

Date.	Position-Angle.	Distance.	Remarks.
1874	° ′	″	
June 29	30 19	8·19	Good definition; full moon; measures of distance not good; power 140; telescope $7\frac{1}{4}$.
	30 12	8·17	
	30 0	7·93	
	30 8	8·21	
	30 9	8·08	
	29 53	8·34	
	30 5	8·45	
	29 44	8·10	
	29 50	8·47	
	29 58	8·32	
Means	30 2	8·23	
1875	...	...	Observer away in Europe.
1876			
May 23	45 5	4·39	Stars tremulous, and very watery; power 180; aperture 6 inches; first measures with $11\frac{1}{2}$ inches.
	46 30	4·52	
	46 0	4·62	
	46 15	4·55	
	45 40	4·52	
	46 25	4·57	
	46 35	4·50	
	45 40	4·52	
	46 10	4·48	
	46 30	4·27	
Means	46 5	4·49	
June 8	47 47	4·2	Moderately steady; one disk seems about $\frac{1}{3}$ more in diameter than the other; telescope $11\frac{1}{2}$; power 544.
	48 0	3·81	
	47 52	4·30	
	47 10	4·23	
	48 28	4·70	
	47 42	4·41	
	48 15	4·38	
	48 10	4·22	
	48 8	4·20	
	47 10	4·34	
Means	47 52	4·20	

Date, 1877	Position-Angle. ° ′	Distance. ″	Remarks.
July 5	72 56	2·713	Aperture 8 inches; power 450; stars dancing; telescope 11½.
	72 56	2·803	
	72 46	2·445	
	73 2	2·766	
	72 46	2·731	
	72 59	2·481	
	72 21	2·642	
	73 24	2·392	
	72 56	2·427	
	72 36	2·570	
Means	72 52	2·597	
July 7	72 57 mean		6 measures; power 450.
	72 31 „		8 „ „ 800.
July 20	78 57	1·818	Telescope on west side of pier; star 2 hours before meridian; definition not good; aperture 5 inches; power 500; telescope 11½.
	79 40	2·179	
	80 25	2·161	
	80 40	1·999	
	79 33	2·179	
	79 15	1·999	
	78 40	2 089	
	78 7	2·071	
	79 28	2·071	
	79 45	2·143	
Means	79 27	2·071	
July 24	75 40	2·269	Aperture 7 inches; power used 800; telescope on east side; star 2 hours past meridian; telescope 11½ inches.
	76 30	2·071	
	75 55	2·125	
	75 35	2·071	
	76 12	2·287	
	75 45	2·105	
Means	75 56	2·155	

Date. 1877	Position-Angle. °	′	Distance. ″	Remarks.
July 25	76	50	2·089	Aperture 5 inches; power 800; telescope on east side of pier; definition not very good; stars dancing. Great care taken with these observations, but the position-angle is very difficult, owing to the motion or unsteadiness of the stars. Clouds were passing, and at times obscured both stars, but oftener only α^2, which I estimate as fully one-third, or nearly one-half, less than α^1. The varying thickness of the clouds enabled me to estimate the relative brilliance.
	75	0	2·197	
	77	35	2·089	
	77	3	2·197	
	76	28	2·161	
	76	5	1·927	
	76	20	1·999	
	75	20	2·053	
	77	40	2·215	
	77	30	2·143	
	76	30	2·179	
	75	15	2·017	
	76	10	2·251	
	75	30	2·071	
Means	76	22	2·113	

Sydney Observatory,
July 27, 1877.

Observations of the Lunar Eclipse, 1877, *August* 23. By the Rev. Samuel J. Johnson.

The total eclipse of the Moon was seen here as well under an English as under an oriental sky, not a cloud intervening throughout. I employed a power of 70 on $2\frac{1}{4}$ in.

9.10 Penumbra dimmed the N.E. quadrant of the Moon considerably. At 8.45 I had not been able to satisfy myself about the presence of it. Precise time of commencement difficult to determine. At 9.15 the shadow was evidently impinging on the neighbourhood where *Olbers* is marked.

9.18$\frac{1}{2}$ Immersion of *Grimaldi*.

9.22$\frac{1}{2}$ Shadow reached *Aristarchus*.

9.32$\frac{3}{4}$ *Copernicus* reached. For 3 min. or 4 min. an orange tint has been visible at the edge of the Moon. *Aristarchus* comes out most distinctly in the shadow.

9.39$\frac{3}{4}$ *Plato* reached.

9.40$\frac{3}{4}$ *Archimedes* reached.

9.49$\frac{1}{4}$ *Tycho* reached. *Aristoteles* same time. Copper tint readily seen with unassisted vision.

9.51 Immersion of *Tycho*.

9.55 The three ψ's in *Aquarius* coming into view to the naked eye.

10.5 So-called seas in the eclipsed Moon beginning to be very prominent. *Mare Serenitatis* standing out nearly black, darker than any other part of the lunar surface.

10.13¼ Immersion of *Mare Crisium*. *Mare Crisium*, *Mare Fœcunditatis*, and the region south of them of a greenish hue. The rest of the eclipsed disk of a coppery tint.

10.18·2 Emersion of a star about mag. 7½ from a point in a line with south extremity of *Mare Crisium*. Angle about 100°.

10.20 Total obscurity.

10.24·9 Star mag. 7 occulted, angle about 80°. It exhibited the illusion of projection more plainly than I have ever noticed, appearing to lie within the Moon's limb 3^s or 4^s.

11.8·0 Emersion of small star mag. 8. Angle about 110°.

11.15 The central regions darkest, being about the time of mid-eclipse; the illumination round the borders tolerably uniform now.

11.45 Crescent of yellow light on Moon's eastern limb. *Mare Crisium*, *Fœcunditatis*, *Nectaris*, *Tranquilitatis*, *Serenitatis* in a smoky gloom; above and below this region the prevailing tint orange.

12.4¼ First streak of sunlight. This outbreak was so clearly marked that it might have been noticed by the naked eye within 3^s or 4^s of the instant the telescope showed it.

12.7¼ Emersion of *Grimaldi*.

12.14¼ Emersion of *Aristarchus*.

12.27½ Emersion of *Copernicus*.

12.30½ Emersion of *Plato*.

12.31¼ Emersion of *Tycho*.

12.35 Emersion of *Archimedes*. Milky Way beginning to fade out of sight, now half the Moon is uncovered.
A slight brownish tinge mingling with the grey could be detected until 12.55.

13.0¾ *Mare Crisium* began to emerge.

13.5 Emersion of the *Mare Crisium*.
A few degrees north of this, the shadow left the Moon about 13.8½.

(Angles of Stars occulted reckoned same way as in *N.A.*)

There was an absence of that flickering light on the reddened disk of the Moon which I noticed last February, and which was probably due simply to the undulations of our own atmosphere, but which Professor Dorna of Turin ascribed to the action of a lunar aurora, saying that the refraction of the Sun's rays within the cone of the Earth's shadow was not an adequate explanation. (See *L'Opinione Nazionale*, March 3).

I had requested another observer, only 35 sec. long. further east than here, to note the time of the first outbreak of sunlight on the Moon, as a simultaneous observation, and the result gave a difference of longitude almost precisely accurate.

Upton Helions Rectory, Crediton.

On the Spectrum of Comet b 1877 (*Winnecke's*) *and of the Eclipsed Moon, observed at the Royal Observatory, Greenwich.*

(*Communicated by the Astronomer Royal.*)

The position of Comet *b* 1877 was so inconvenient for observation with the Great Equatoreal when armed with the long Single Prism Spectroscope, that it was found practically impossible to obtain any measures of the bands in the Spectrum, though on May 15 the Dun Echt Observations (*Monthly Notices*, 1877, June) were so far confirmed that the spectrum of the coma was found to consist of three bands in the neighbourhood of the three principal carbon bands, wave-lengths 4834, 5203, and 5607, whilst that from the nucleus appeared to be continuous. For more exact determination of position, a small Half Prism Spectroscope, giving a dispersion of 20° from A to H with a magnifying power of 9 on the viewing telescope, was used, and this, being only 16 inches in length and consequently much shorter than the other spectroscope, allowed sufficient room for the observer within the polar axis. With this greater dispersion the spectrum of the nucleus no longer appeared continuous, and the wave-length of the brightest band was determined (by six indirect comparisons with the carbon band 5203) to be 5178, with a probable error of 5 tenth-metres. The measures were made by turning the half-prism by means of a screw, so as to bring the cometary band to coincide with the bright reference line formed by the image of the comet on the slit, and then comparing the latter with the band in the carbon spectrum.

During the Eclipse of the Moon on 1877 August 23, the spectrum was observed with the Single Prism Spectroscope during totality and also during the partial phase, when the portion of the Moon's disk still in the umbra was repeatedly compared with the part which had emerged. During totality (about 11^h G.M.T.) a strong absorption band was seen in the yellow, and the red and blue ends of the spectrum were

completely cut off, whilst the orange was greatly reduced in intensity. The yellow and green were comparatively bright, and in fact appeared at a first glance to constitute the whole visible spectrum. The wave-length of the more refrangible edge of the strong absorption band was found, from a mean of 9 measures, to be 5624 ± 5, and at about 11^h it extended to wave-length 5900, i.e. as far as D. As the end of the total phase approached ($12^h\ 4^m$), the band became narrower, its breadth being only twice the interval of the D lines at $11^h\ 45^m$, and at $12^h\ 20^m$, during the partial phase, it was reduced to a mere line on the eclipsed portion. This band is coincident with the strong band δ of the atmospheric spectrum as given by Brewster and Gladstone, which is peculiarly characteristic of the spectrum of light which has passed through a thick stratum of air. The red end of the spectrum was cut off by a dark band commencing about halfway from D to C, in which a black line was suspected. About the middle of totality a dark band, commencing at 5080 + (near band ι of the Brewster-Gladstone spectrum) cut off all the rest of the spectrum, but later on at $11^h\ 30^m$ the spectrum was visible as far as about 4930 (the position of band κ in the atmospheric spectrum). After the end of totality the red and blue ends of the spectrum from the eclipsed portion became visible beyond these limits. The appearance of the spectrum of the part clear of the umbra, though still in the penumbra, was totally different, even when reduced to the same degree of faintness by closing the slit. In this case the spectrum faded out as a whole from beyond D to near G in the violet.

The part of the Moon examined when the band δ was darkest was the region of *Mare Nectaris* and *Mare Fœcunditatis*, and the band could be seen only on the darkest part of the Moon when *Kepler* was just emerging from the umbra, growing rapidly fainter as the spectroscope was moved away towards the bright part.

The light by which the eclipsed Moon is visible would thus appear to have passed through a great thickness of the earth's atmosphere, giving rise to the peculiar copper colour.

The observations were made by Mr. Christie and Mr. Maunder.

Royal Observatory, Greenwich,
1877, *August* 28.

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